Firing Systems: Handling and Preparation of Noble Fuels

D. Pauling
PT 98/14353/E

1. INTRODUCTION

Noble fuels are coal, fuel oil and natural gas. Handling and preparation of those fuels has to fulfill certain requirements in order to produce similar combustion conditions for those different fuels and avoid incomplete combustion, e.g. CO at kiln inlet or local reducing conditions due to combustion of fuel particles in the clinker bed.

For coal firing the main types of firing systems are described (direct, semi-direct and indirect firing). For pulverized coal dosing and transport to the burner the important design criterias are outlined. The required coal dust qualities for a good combustion in the cement kiln are described.

For fuel oil firing, preparation and heating systems are outlined. The required fuel oil qualities (pressure, viscosity and temperature) are given.

For natural gas firing, preparation and safety precautions are described.

Burners, injection characteristics and flames are not subject of this paper (see paper: "Burners and Flames").

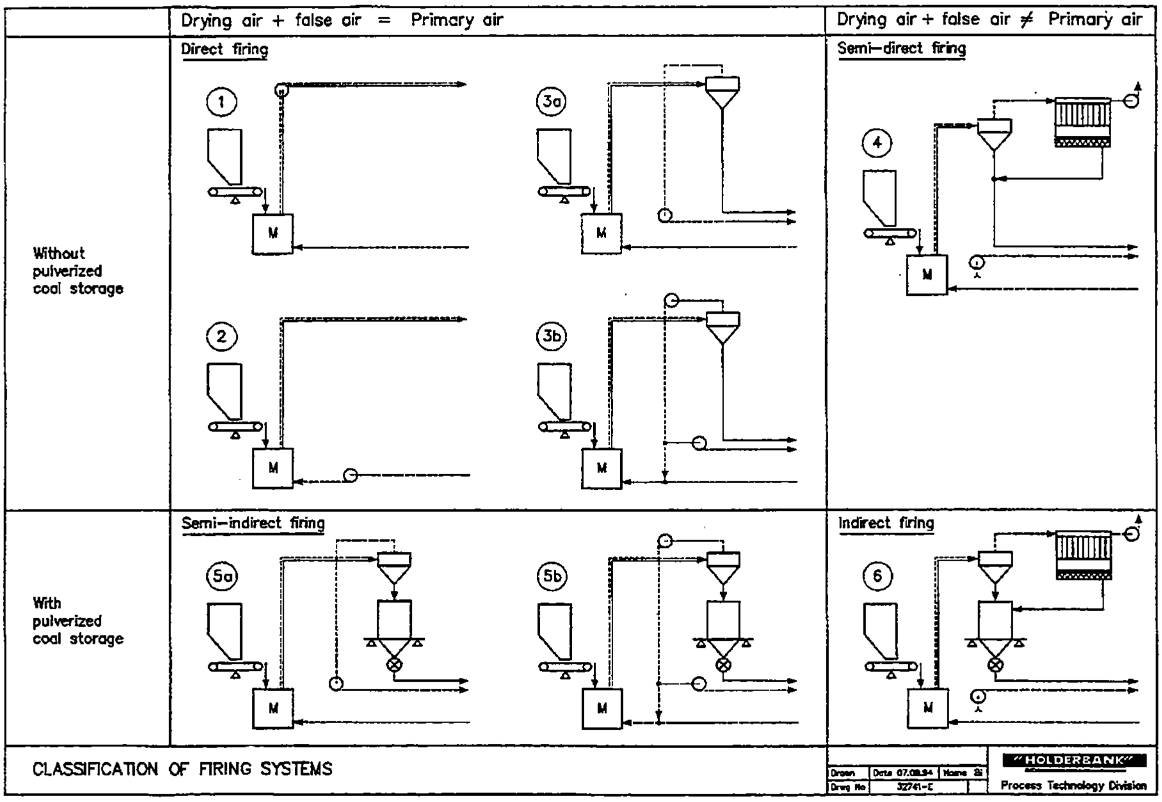
2. COAL FIRING SYSTEMS

Before the coal is fired, it has to be prepared according to the required fineness. The coal has to be dried to 0.5 - 1.5 % residual moisture content, since moisture in the coal means loss of calorific value, as the water has to be evaporated and heated up to flame temperature. Coal drying is done simultaneously with the grinding.

2.1 Classification of Coal Firing Systems

With reference to gas and material flow, the coal firing systems can be classified into four main groups which in total sum up to six individual systems (Fig. 1).

Figure 1: Classification of Coal Firing Systems



System 1 - Direct firing

Represents the most simple case. The coal is ground in the mill, dried and blown into the kiln together with the drying gases.

System 2 - Direct firing

Basically describes the same solution with the exception of the mill working under positive pressure. This solution is generally applied to protect the fan when processing abrasive coal.

System 3 - Direct firing

In system 3, the fan is protected by separating the pulverized coal in a cyclone and feeding it after the fan into the primary air stream.

System 3a - Direct firing with recirculation

Same as system 3, but with recirculating drying air. This arrangement allows reduced primary air ratios.

System 4 - Semi-direct firing

Has little technical significance since the solution with intermediate storage of coal would generally be given preference.

System 5a - Semi-indirect firing

With system 5a, the kiln can be operated independently of short mill shut downs since the pulverized coal is stored in an intermediary storage bin. The exhaust air from the mill enters the kiln as primary air.

System 5b - Semi-indirect firing with recirculation

Same as system 5a, but with recirculating drying air. This arrangement allows reduced primary air ratios.

System 6 - Indirect firing

In system 6, the grinding installation is completely separated from the kiln. The pulverized coal is stored in an intermediary storage bin and the exhaust air from the mill is released through a filter into the atmosphere. By this way, the kiln operation is completely independent from the combined drying and grinding operation.

Major Advantages / Disadvantages of the Different Coal Firing Systems:

	Direct firing		Semi-indirect firing		Indirect firing
	Conventional	modified	Conventional	Modified	
	System 1 and 2	System 3a	System 5a	System 5b	System 6
Advantages	• Simple design • Low risk of explosions • Simple extinction of fire in the in the grinding system by stopping coal feed. No spread of fire into silos	• Lower primary air ratios and thus lower heat consumption compared to conventional • Independent primary air fan	• No exhaust gas, therefore no filter required, thus lower risk of explosions than with indirect firing • Short mill shut down not = kiln shutdown • Only one mill required for several kilns • Easy sampling for fineness control	• Lower primary air ratios and thus lower heat consumption compared to conventional • Independent primary air fan	• Simple flame control • Low primary air ratio • Water vapour from coal drying is not introduced into the kiln • Short mill shut down not = kiln shutdown • Only one mill required for several kilns • Easy sampling for fine-ness control
Disadvantages	• Combined operation with the kiln, therefore often not optimal operating conditions. • Mill shutdown = kiln shut-down • Number of kilns = number of mills thus reducuing the advantage of lower investment cost if several kilns are installed • High primary air ratio up to 30% • Slow control loops, long dead time • Sampling for fineness control difficult	• More complex installation requiring additionally: primary air fan, longer ducting	• More complex installation requiring additionally: cyclones , pulverized coal silos, pulverized coal feeders, measuring and control system • High primary air ratio up to 30%, during start up and shut down of grinding plant disturbed kiln operation • Investment cost higher than with a direct firing system (valid for one kiln only) • Risk of self-ignition of the pulverized coal in the storage silo	• More complex installation requiring additionally: primary air fan, longer ducting	• More complex installation requiring additionally dedusting filter • Investment cost higher than with a direct firing (valid for one kiln only) • More vulnerable to fires and explosions in gas ducts and filter • Risk of self-ignition of the pulverized coal in storage silo

Impact of Firing System on Kiln Operation:

- Direct firing systems tend to enhance coal fluctuations and therefore disturb combustion.
- If the mill vent air enters the kiln as primary air as it is the case with the direct- and semi-direct firing, the primary air ratio is higher than required for optimum combustion. At a given excess air factor, the primary air ratio has a direct influence on the heat recuperation efficiency of the cooler and finally on the overall kiln heat consumption. If the heat consumption can be reduced, the exhaust gas quantity is automatically decreasing, which offers potential for a capacity increase.
- Another very important advantage of lower exhaust gas quantities is the effect of decreased gas velocities in the kiln. This on the other hand has the benefit of lower dust generation for wet kiln systems.
- With a direct firing system the water vapor from coal drying enters the kiln with the primary air. The water vapor has no direct influence on the combustion process, but increases the kiln exhaust gas quantity accordingly. A water content of 15% in the coal increases the exhaust gas quantity of a dry process kiln by approx. 1.5% and of a wet process kiln by 1.2 %.
- At the same time, the flame stability may decrease as a result of dilution of the primary air.
- Flame shape is strongly influenced by the type of firing system. An indirect system will not only support a more stable flame, but also a shorter one, which results in smaller, more even distributed alite crystals with higher reactivity. Benefits are better quality of the clinker and a lower energy demand for the cement grinding.
- For new projects direct firing will not be selected anymore because of the above mentioned disadvantages. Today indirect firing systems are "State of Technology". Conversion projects from direct to indirect firing for existing installations can not always be financially justified on the basis of reduced thermal energy consumption. In countries with low coal prices, pay back times of several years must be expected. However, what can make a conversion project interesting, are the positive effects on kiln operation and thus product quality.

2.2 Quality of Coal Preparation

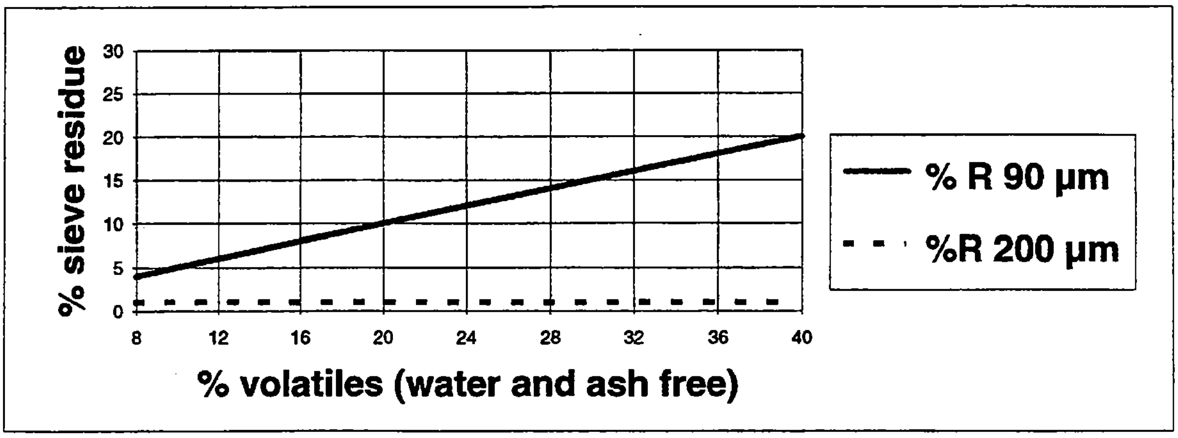
Inadequate coal preparation (fineness) can result in both burn-out problems (CO formation) and the presence of fuel in the material bed (increased volatility of sulfur).

The combustion time of coal depends on the content of volatile elements.

Fig. 2 shows the principal requirements for coal fineness in function of the volatile content.

Figure 2: The Grinding Fineness of Coal in Function of its Volatile Content

Rule of thumb: **% R 90 µm = 1/2 (% volatiles)**



The aim is to comply with the following simple rule as an upper limit:

- **Residue on the 90 µm sieve < ½ (% volatile components)**
- **Residue on the 200 µm sieve < 2%**

For low volatile and difficult to burn coal types such as petrol coke and anthracite, the above mentioned rule has to be tightened:

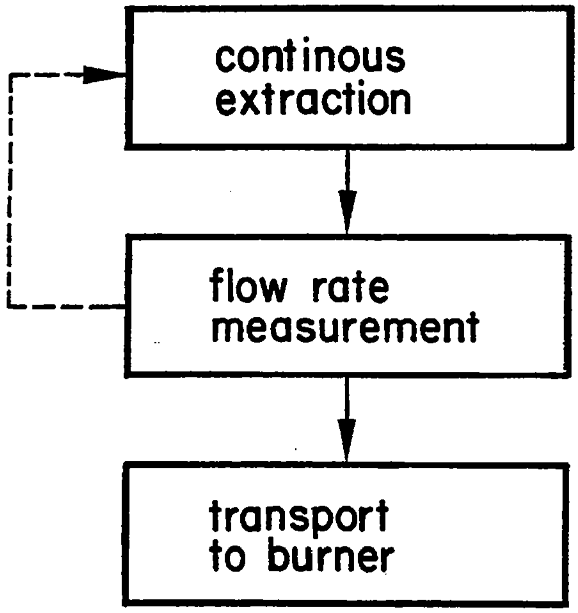
- **Residue on 90 µm sieve for petrol coke and anthracite < 5 %**
- **Residue on 200 µm sieve for petrol coke and anthracite < 1 %**

It has to be pointed out, that both values, the residues on 90 µm and on 200 µm are important. The 90 µm values influence flame length and CO formation, excess residues on 200 µm create reducing conditions in the material bed and can be responsible for increased volatilization of sulfur.

2.3 Pulverized Coal Dosing

For coal firing, in order to obtain perfect fuel feed, the entire feed system - from discharge from the coal dust silo, through weighing and dosing, to coal dust transport to the burner - must function as well as possible (Fig. 3).

Figure 3: Pulverized Coal Dosing



2.3.1 Feed Bins for Pulverized Coal

The feed bin design has a decisive impact on feed rate control. A feed bin design ignoring a product's flow characteristics may result in inconsistent discharge rates due to problems such as arching, erratic flow and flushing, conditions that can not be corrected by any feeder system.

Design of feed bin, activation and discharge:

- The capacity of the feed bin should be sufficient for at least 15 but not more than 60 minutes of kiln/precalciner operation
- The bin has to be designed for mass flow.
- The activated discharge opening section must be large enough to prevent bridging (at least 1200 mm in diameter for circular outlets and 600 x 1800 mm for slotted discharges).
- The discharge opening should be activated preferably by using mechanical discharge device such as paddle or agitator.
- Pulsed aeration systems for flow activation are only suitable for bins feeding loss-in-weight dosing systems. As a compromise aeration can help to solve discharge problems at existing bins, but should be avoided for new bins.

2.3.2 Weighing and dosing of pulverized coal

Proper weighing and dosing requires a uniform coal dust supply (feed bin discharge; see above). It is necessary to distinguish between accuracy of weighing and short term variations.

The dosing system should meet the following requirements:

- Weighing accuracy: +/- 2% is normally accepted.
- Short term variations (referring to 10 sec. measurements): < +/- 1% (short term variations are responsible for CO peaks)
- Long term variations (approx. 10 min. to 1 hour): < +/- 0.5%
- Sensibility: < +/- 0.5%
  (Example: A dosing system with a maximum capacity of 5 t/h has to be capable to handle set point changes of +/- 25 kg/h).
- Adjustment range: 1:20 (of the maximum capacity).

The best indicator for the accuracy of the dosing is the oxygen level at kiln exit. Poor dosing of coal dust leads to big fluctuation of the oxygen concentration.

2.3.3 Most Common Pulverized Coal Dosing Systems

At present two systems are on the market which offer the best solutions for dosing pulverized coal.

- Rotor Feed Scale (Pfister) Fig. 4
- Coriolis Scale (Schenk) Fig. 5

Only second choice are the following systems:

- Loss-In-Weight System (complex setup requiring skilled maintenance)
- Impact-Flow Meter (limited accuracy)

Figure 4: Rotor Feed Scale (Pfister)

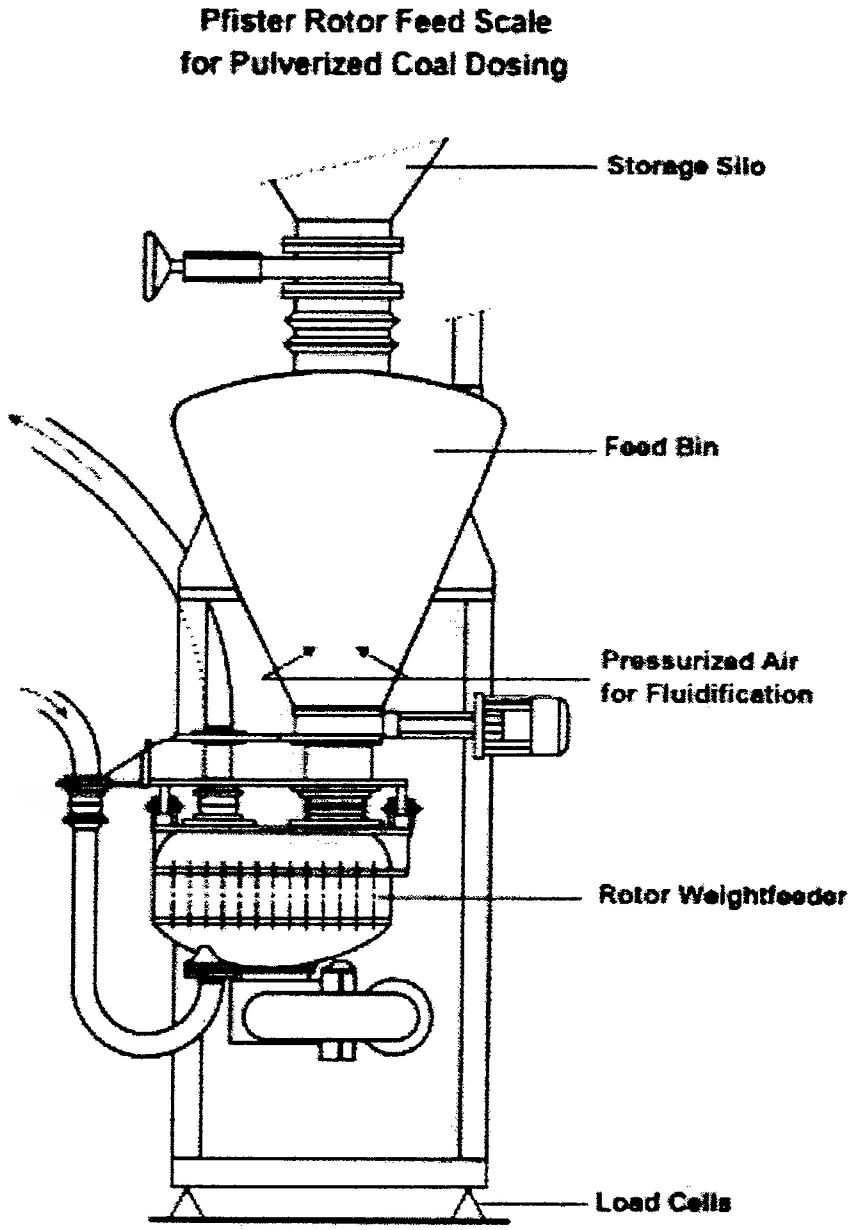
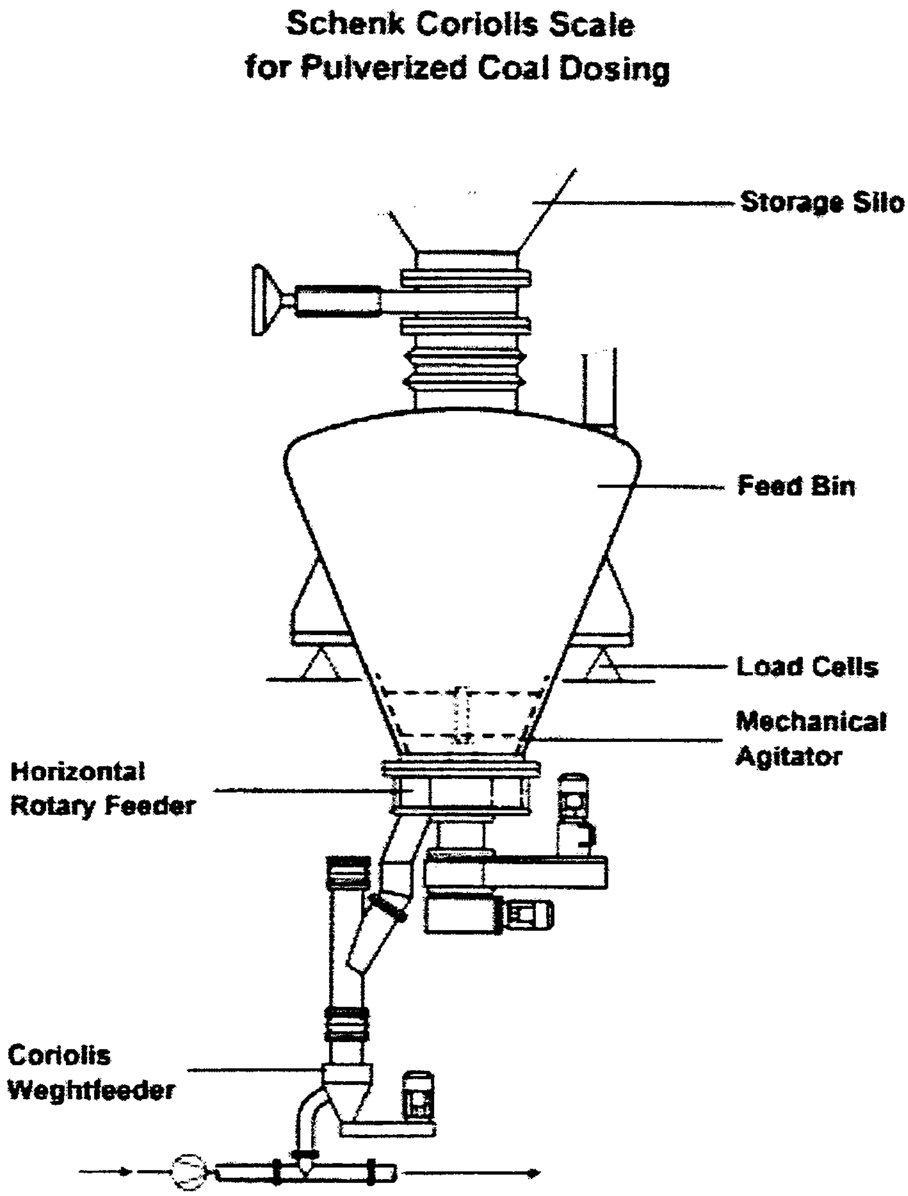


Figure 5: Coriolis Type Feed Scale (Schenk)



2.4 Pneumatic Transport of Pulverized Coal to the Burner

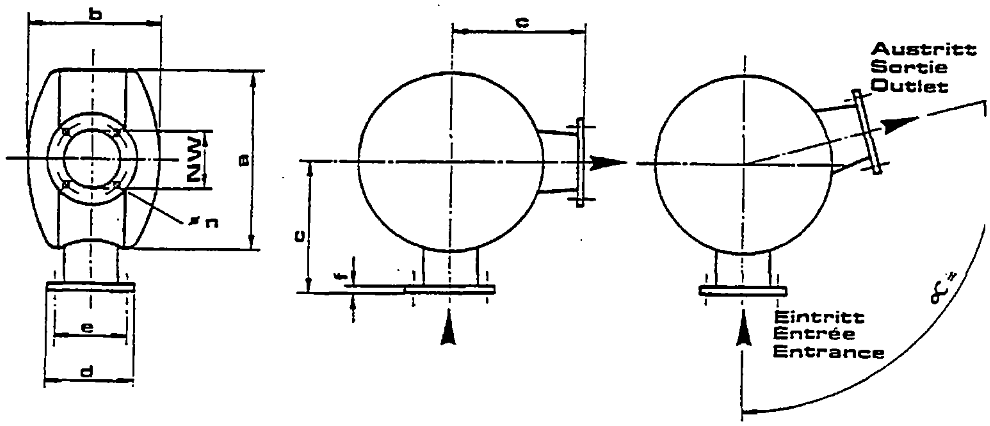
The highest accuracy of the dosing and feeding system is not useful for the kiln operation if the transport to the burner is not designed well.

What is required is a high accuracy at the feed point to the process. This means that a careful design of the pneumatic transport of the pulverized coal to the burner is of utmost importance too.

The coal dust transport should meet the following design criteria:

- Pneumatic transport velocity to burner is one of the most critical items for regular coal flow. To avoid pulsations caused by pocket formation in the pneumatic transport line, the transport velocity (from feeder to burner) should be in excess of 32 m/s.
- The fuel load carried by the air is not a critical value. Normal loads lie at about 5 kg/m^3, but values of up to 12 kg/m^3 are found without any operation problems.
- Fluctuations caused by the feeding device of coal to transport air (pneumatic pump, rotary air valve) have to be avoided by adequate design of the feeder (sizing, number, arrangement of rotary feeder cells, dedusting).
- Pressure fluctuations in the pneumatic transport: < +/- 5 mbar.
- Transport lines should run horizontally and vertically (no in-/declining sections). Long curves should be avoided because they lead to segregation of the coal dust through centrifugal forces and this in turn leads to plugging. Diversion pots have proved the best solution in three respects: 1. low wear and tear 2. low loss of pressure and 3. the coal dust is remixed with the transport air at every turn (Fig. 6).
- Maximum number of turns: 5 (preferably by diversion pots); first turn after the dosing no diversion pot
- Total length of the pneumatic transport line: < 120 m

Figure 6: Diverting Pots for Pulverized Coal Transport (Units: mm)



NW	a	b	c	d	e	f	⌀	n	ca.kg
80	400	280	280	190	150	16	18	4	20
100	400	330	325	210	170	16	18	4	24
125	400	400	330	240	200	18	18	8	26
150	600	450	440	265	225	20	18	8	50
175	600	450	440	295	255	22	18	8	54
200	700	550	490	320	280	22	18	8	76
250	700	630	450	375	335	24	18	12	80
300	800	690	680	440	395	24	22	12	145
350	800	750	495	490	445	26	22	12	160

3. OIL FIRING SYSTEMS

The handling of fuel oil in a cement plant can be subdivided into the following steps:

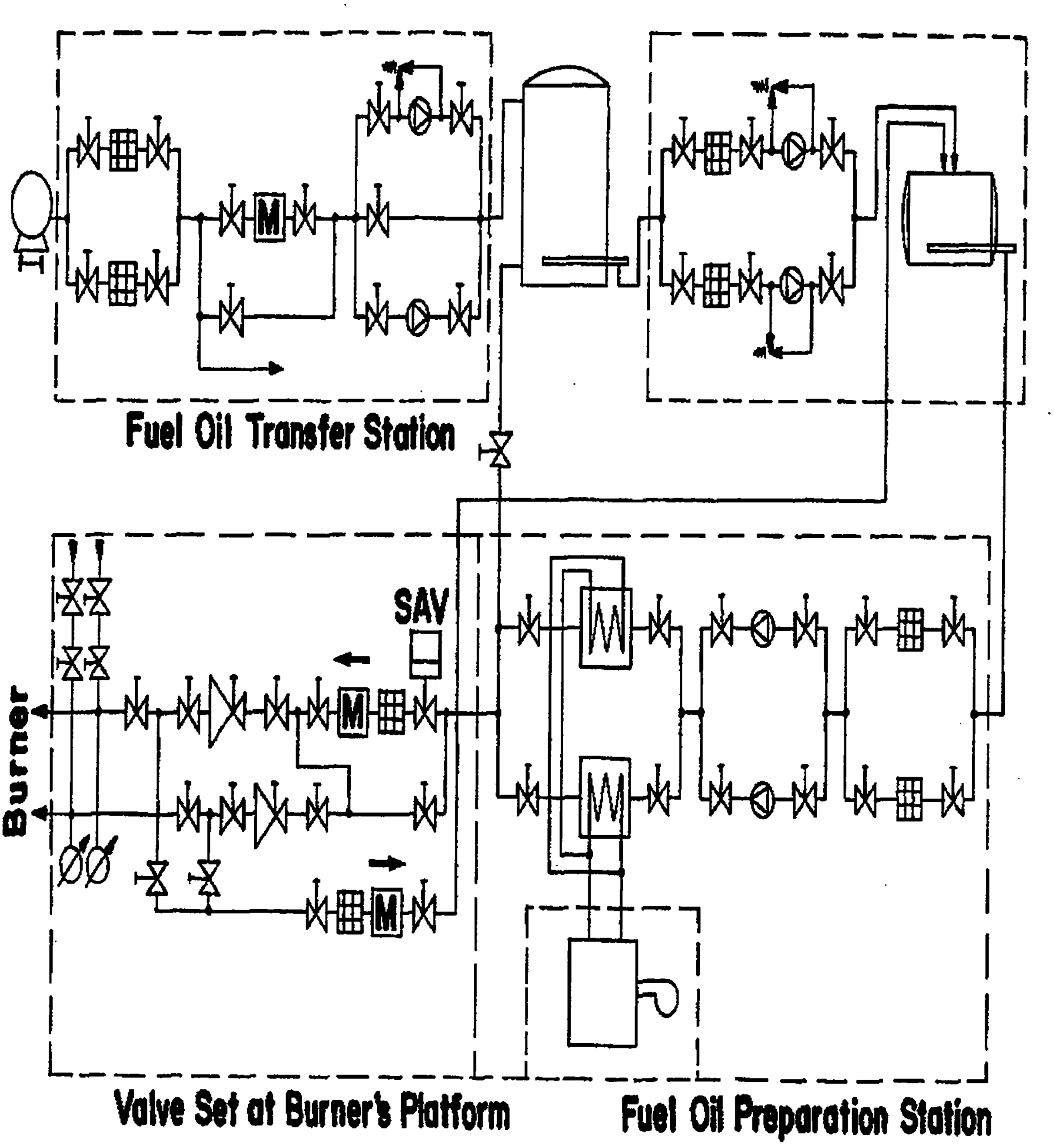
1) Transfer to the storage tanks
2) Storage and extraction from storage tanks
3) Preparation, measuring, dosing
4) Atomization and combustion

The last point will be delt with in the separate paper: "Burners and Flames".

3.1 Fuel Oil Transfer from Delivery Point to the Storage Tank

For easy handling, fuel oil must have a temperature of about 50 to 60°C. If it is delivered at lower temperatures, which - due to the insulation of the wagons - is rather seldom, it has to be heated up. This can be done by circulating saturated steam (8 to 12 atm), thermal oil or electricity through the heating coils at the bottom of the railway wagons or trucks. Heating time depends on the boiler output, on the capacity of the wagon, on delivery temperature of the oil and on ambient temperature and lies between 2 and 6 (12, 24) hours (200 to 250 kg/h of steam is needed for a 20 tons capacity wagon). It is therefore common practice to do this - whenever required - in the afternoon, to heat up the oil during the night and to empty the wagons in the following morning. Via coarse strainers (for pump protection) the fuel oil is then pumped to the storage tanks (Fig. 7).

Figure 7: Fuel Oil Handling



3.2 Fuel Oil Storage

The main storage requirements depend on the situation of the plant with respect of the fuel oil supply possibilities. A few plants are located sufficiently close to a refinery so that the oil is received by pipeline, directly from the refinery. Such cases require a minimum storage capacity.
Where oil is delivered by truck or by rail, typical main storage capacities allow a kiln operation of 2 to 10 weeks. Tanks are usually designed as welded steel constructions. Due to the fuel oil forming an insulating layer on the walls, any particular insulation efforts are unnecessary.
Suction heaters are used to maintain the fuel oil locally - i.e. in the area of the tank suction point - in a pumpable condition, i.e. at temperatures between 50 and 60°C. This is done in order to minimize the rate of deposit forming reactions, which doubles with each 10°C increase in fuel oil temperature.

3.3 Fuel Oil Preparation

Successful burning of oil requires that it is heated to approx. 140 - 170°C (see Chapter 3.4) in order to reduce its viscosity enough to allow it to be properly atomized by pressure atomization.

Heating up of the fuel oil is usually accomplished through an assembly of equipment all contained on a common base. This minimizes expensive piping and valving and centralizes the equipment for ease of maintenance and control.

Due to the foreign matter that all residual oils contain and the high rate of deposits that form at elevated temperatures, resulting in frequent maintenance, all equipment associated with and on the final heat and pump set is duplicated.

Such a set would contain (see Fig. 7):

- 2 strainers with coarse meshes for pump protection
- 2 oil pumps (gear pumps or screw pumps)
- 2 heat exchangers for heating up the fuel oil to atomization temperature
- 2 strainers with fine meshes for control equipment and atomizer head protection

The supply of heat mainly to the heat exchangers of the fuel oil preparation set, but also to the storage tank suction heater as well as to all oil carrying piping can be accomplished by:

3.3.1 Heating with Steam

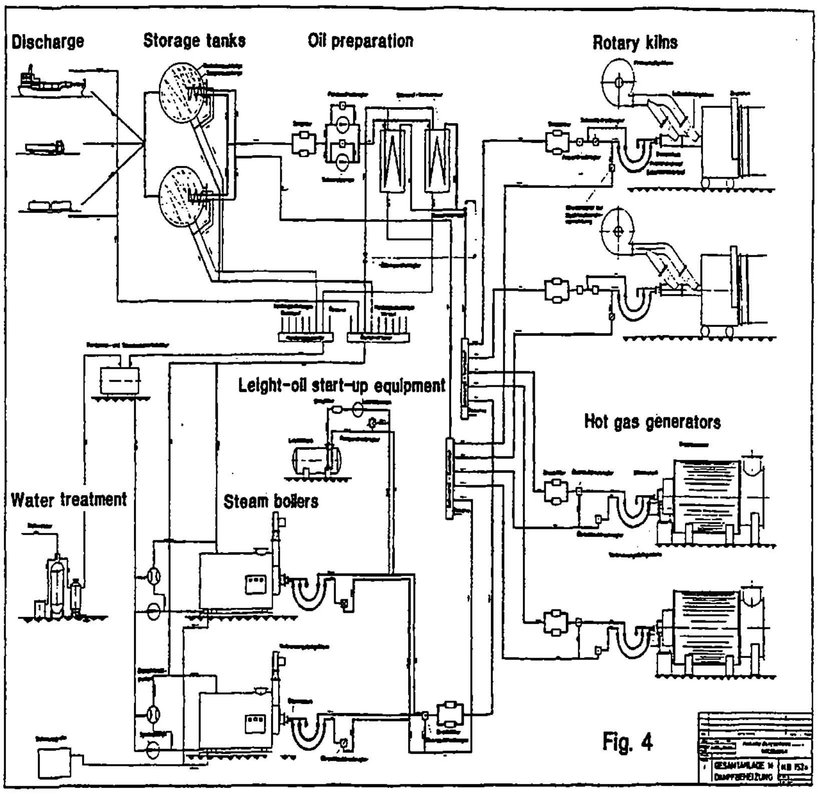
Steam has certainly been the most popular heat carrying medium for oil heating in the past (see Fig. 8). The principal problems associated with steam generation and its use are:

- feed water treatment
- steam trapping
- condensate handling
- high pressure operation
- freezing problems during plant stop

Steam can be produced by:

- conventional oil fired steam generators
- electrical submersion heaters in a pressure vessel
- waste heat based steam generators (e.g. cooler exhaust air)

Figure 8: Fuel Oil Preparation System Based on Steam



3.3.2 Heating with Thermal Oil:

The essential advantages of these inorganic, low flammability oils as a heat transfer medium are:

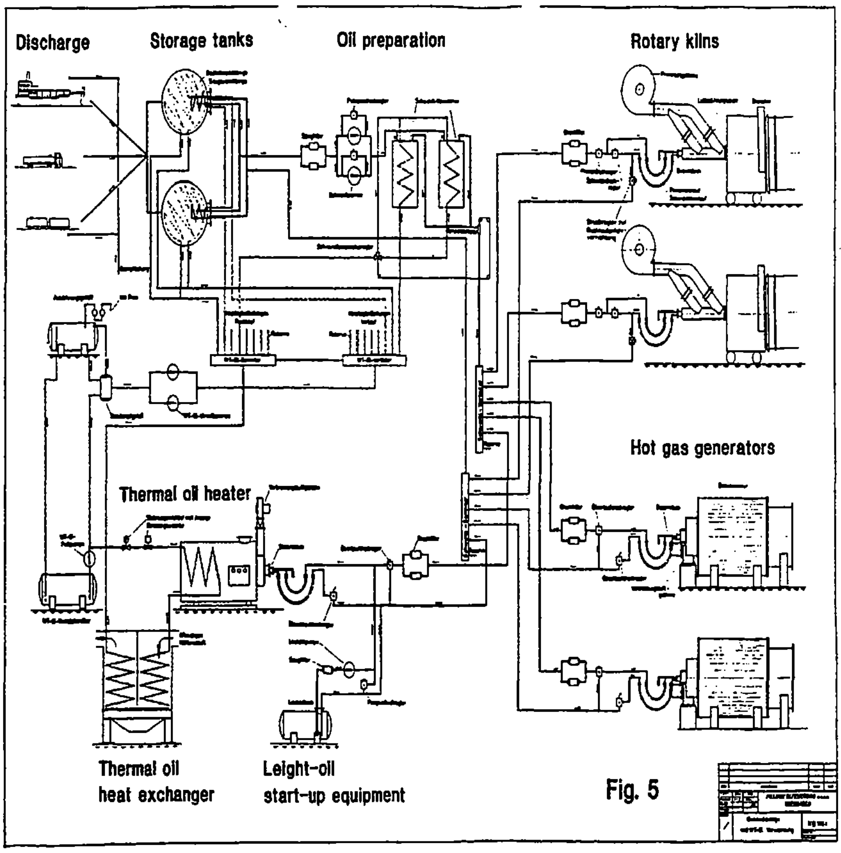
- operation in a constantly liquid phase
- low pressures even at operating temperatures of 250 to 300°C
- no freezing problems

They might be treated up by:

- oil fired thermal oil heaters
- electrical submersion heaters
- waste heat based thermal oil heater (e.g. cooler exhaust air)

Thermal oils are subjected to aging. Their quality has therefore to be checked in regular intervals of about one year. About every five years replacement by a new charge is required (see Fig. 9).

Figure 9: Fuel Oil Preparation System Based on Thermal Oil



3.3.3 Heating with Electricity

Due to high operating costs, direct electrical heating of fuel oils is used for low capacities only. However, it is sometimes used as auxiliary heating for large systems to permit starting when the system is cold.

Electrical power is also used in heating oil lines through "resistance heating". The oil line itself is used as the conductor for high current, low voltage power.

3.3.4 Heating with Flame Radiation

The heating medium in this case is the flame itself. The thermal oil heater is an example of the direct fired heater. Replace the thermal oil with fuel oil and this, then, is the direct fired fuel oil heater.

Since fuel oil cannot be heated to the same high temperature as the thermal oils, burner flame modulation (shape and length) within the heating chamber must be closely controlled to maintain a narrow oil temperature range, e.g. (120°C ± 2+C) over a wide range of oil flow. This close burner flame control must be maintained to prevent overheating and carbonization of the residual oil.

3.4 Quality of Fuel Oil Preparation

For heavy oil combustion, the kinematic viscosity at the burner nozzle must lie within the range of 12 to 20 cSt - preferably 12 - 15 cSt (upper limit 20 cSt) - this ensures that the droplet size needed for good combustion can be achieved. In today's heavy oil market, particularly in the South American OPEC countries, heavy oil is offered which has a significantly higher viscosity than the limit specified by DIN 51 603. It is therefore essential to keep track of the relationship viscosity - temperature and adjust the oil temperature as necessary.

Fig. 10 shows the kinematic viscosity of different fuel oil types in function of temperature. The upper limits for atomization and pumping are indicated.

Fig. 11 shows a conversion table for the different viscosity units.

Furthermore it is important to keep the oil temperature constant within a very narrow range to have a stable flame.

Figure 10: Kinematic Viscosity of Current Fuel Oils

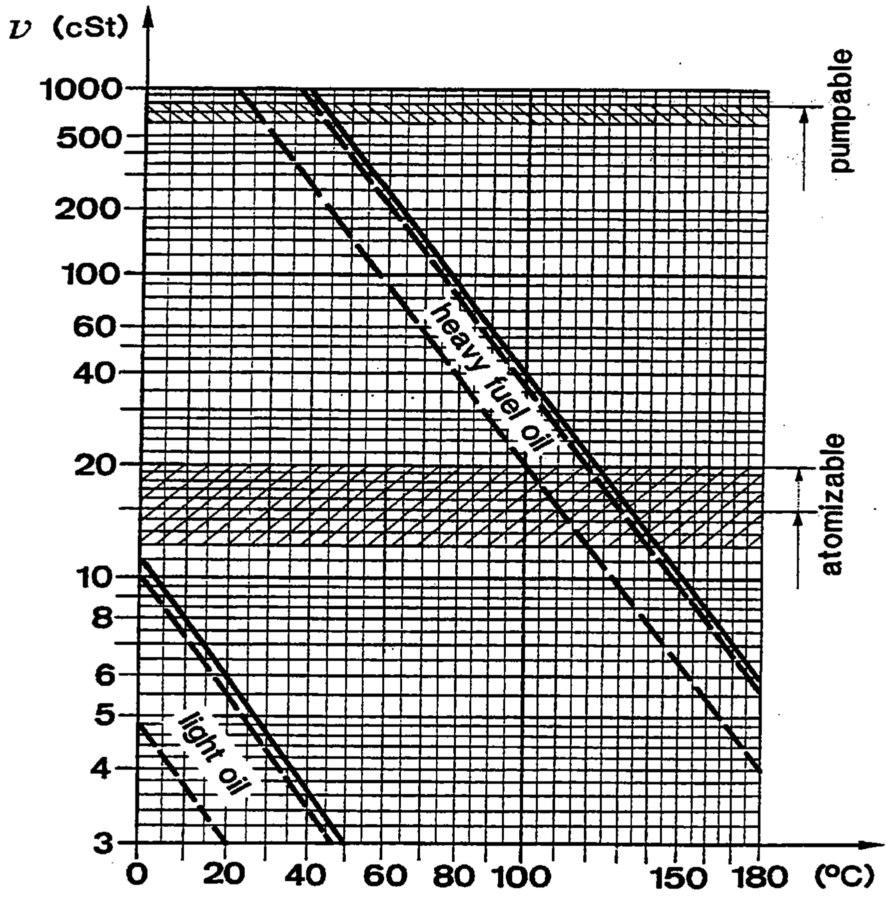
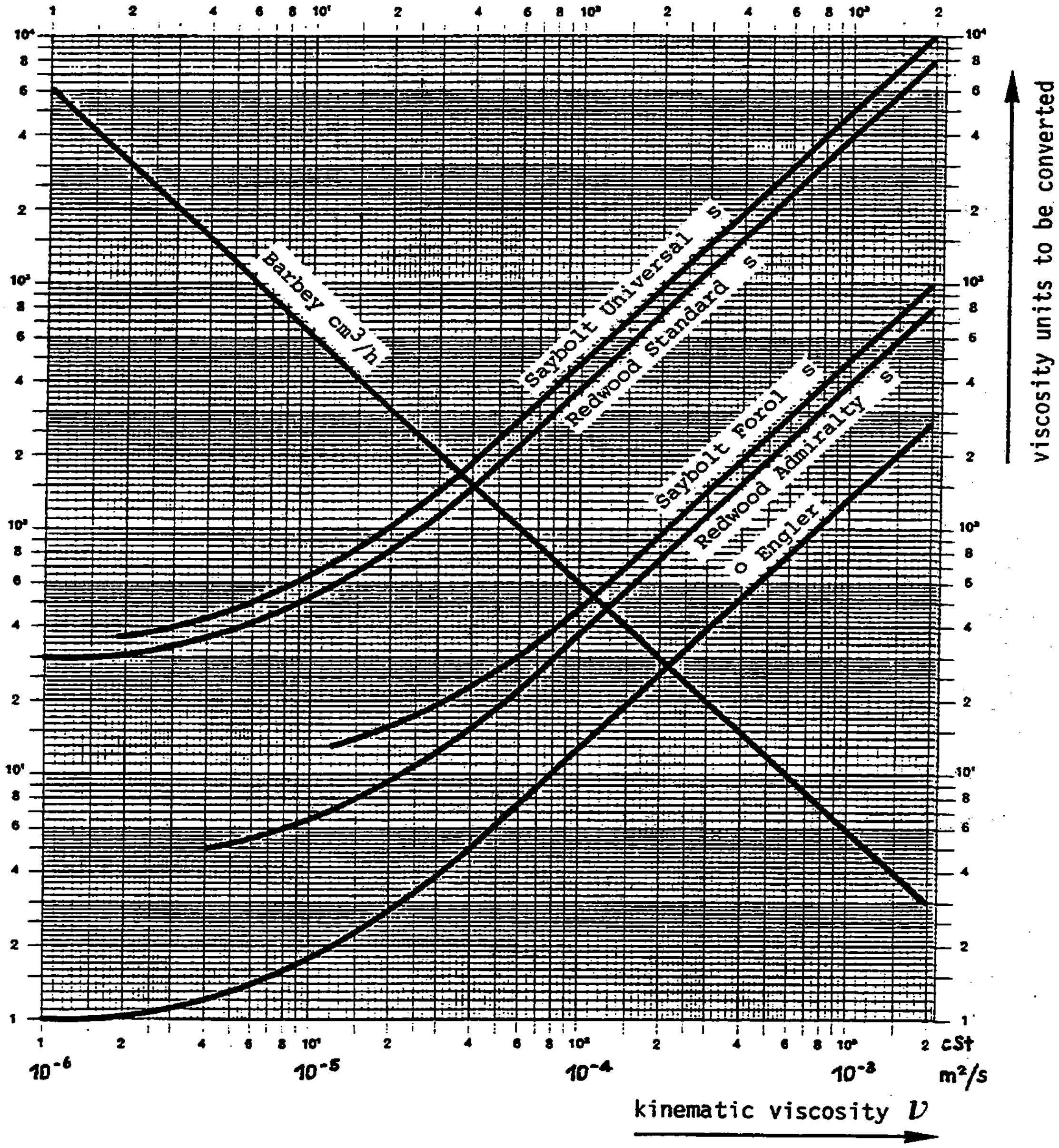


Figure 11: Conversion of Different Viscosity Scales



3.5 Control Loops in the Fuel Oil Circuit

Between storage tanks and fuel oil burners, there are generally four control loops installed, which have to keep constant the following values:

1) Fuel oil temperature at the storage tank suction point.
2) Pressure in the oil circuit line between storage tanks and preparation station (Bypass of a part of the flow back to the storage tank; see Fig 7).
3) Temperature of the fuel oil to be atomized (Preparation Station).
4) Atomizing pressure: Accomplished by means of a bypass valve which leads part of the flow back to the storage tank (see Fig. 7) or by means of variable speed high pressure pumps, which are directly controlled by the oil flow meter.

For burner nozzles with separate feed for axial and radial oil (Pillard, Unitherm), the oil pressure difference for optimum atomizing is set to 1,0 – 1,5 bar. However, as the accuracy of the reading on the oil manometer at the operating pressure of about 40 bar is unsatisfactory, it is recommended that both channels are equipped with flow meters. The pressure (flow characteristics given by the nozzle suppliers) can be taken into account in optimizing atomization.

Furthermore, whenever a kiln stop occurs, the oil lance and the atomizer head have to be cleaned automatically by steam or compressed air in order to avoid overheating and coking of the oil. Continuation of burner cooling has to be assured by having the primary air fan connected to the auxiliary power generators. In cases of prolonged kiln stops removal of the oil lance is preferable, thus, also providing the opportunity to check the condition of the atomizer plate, which is very important for complete combustion.

4. NATURAL GAS FIRING SYSTEMS

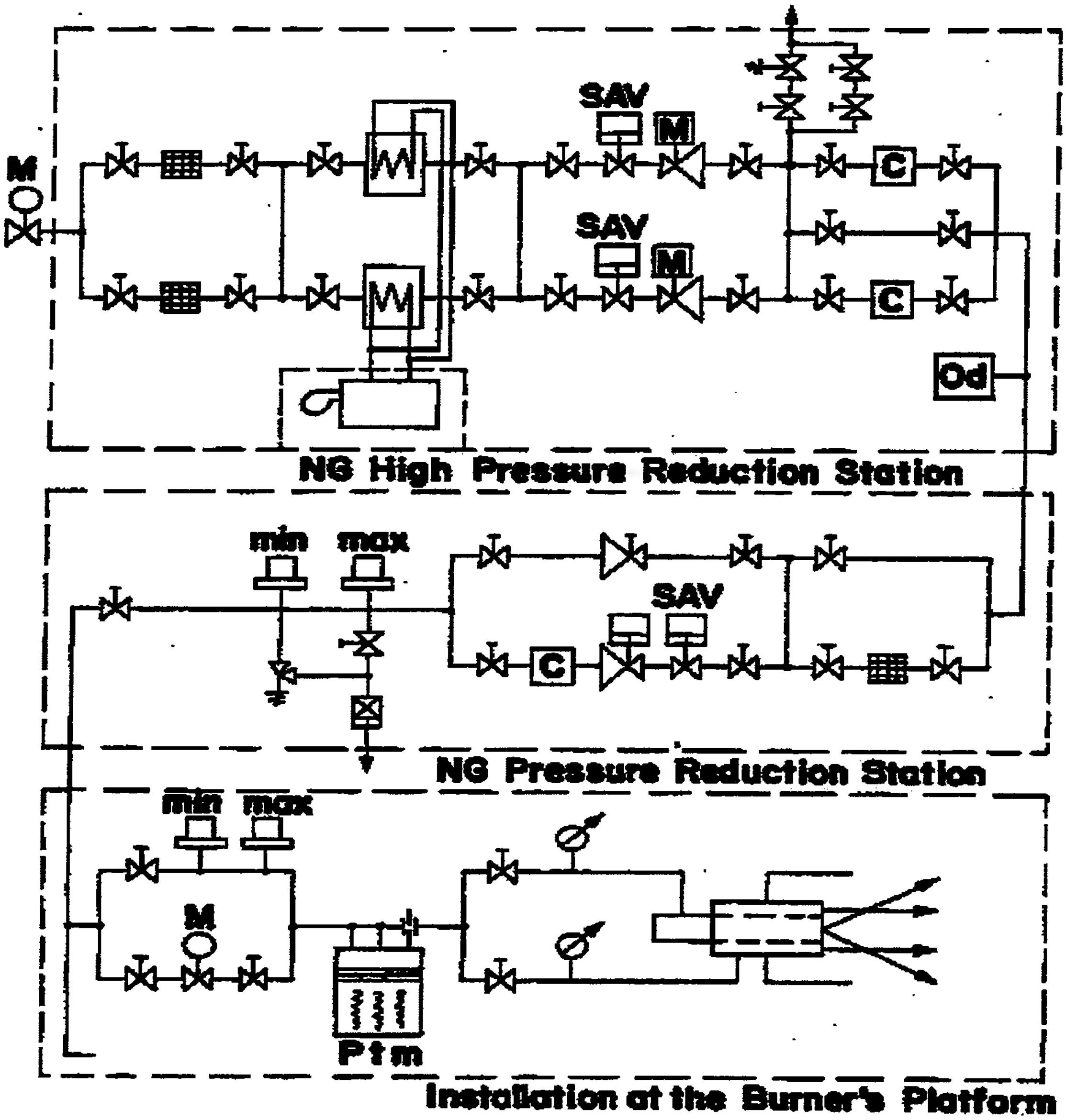
4.1 Natural Gas Preparation

Gas distribution by means of pipelines is accomplished at pressures of 30 to 80 bars. At consumer's site the gas pressure is reduced to the required operational pressure, mostly by means of a two stage expansion process. The first stage takes place in the NG transfer station while the second runs off in the NG pressure reduction station.

As a standard solution the NG transfer station is an independent, self-sustaining installation contained in a separate building (noise suppression). Similarly to the fuel oil preparation plant, all equipment is duplicated and provided with a number of bypass possibilities. The main equipment list is as follows (Fig. 12):

- Remote controlled main shut-off safety valve
- Transfer station inlet filters for protection of equipment from solid particles originating from the pipeline
- Thermal oil heated exchangers aiming to preheat the natural gas to such an extent that the following temperature drop due to expansion will not cause valve internal and external ice formation (Joule - Thompson effect: 0.3 to 0.5°C/bar)
- Safety shut off valves
- Pressure reduction valves (for reduction of the gas pressure to the pressure level of the plant internal distribution network of 3 to 10 bar)

Figure 12: Handling and Preparation of Natural Gas in the Cement Plant

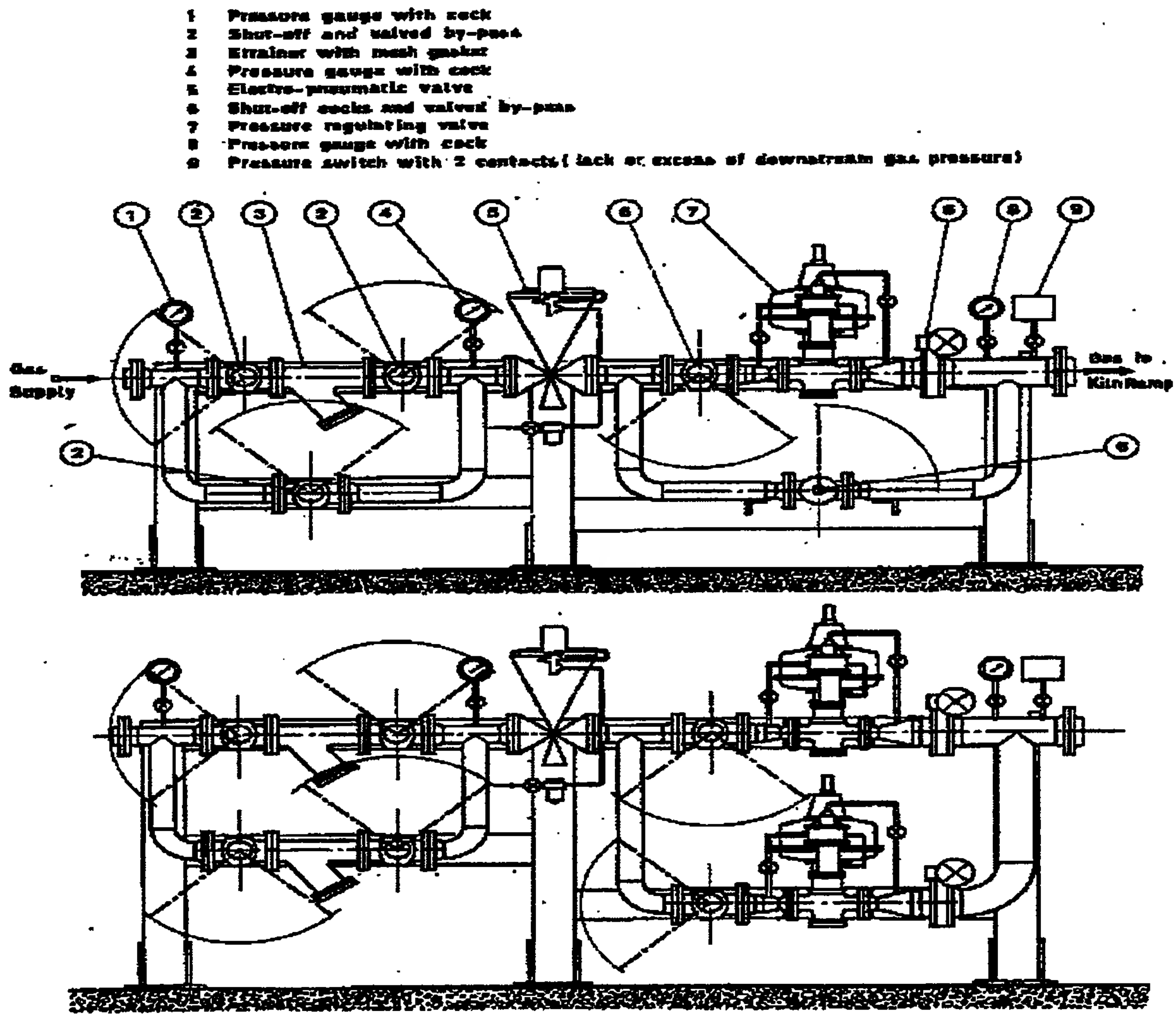


The heat value of the natural gas can be measured and recorded continuously by means of on-line calorimeters. Though this is often not done - plant people tend to rely on the heat values given by the gas suppliers - it would be worthwhile, since in some cases the heat values might vary in range of ±300 kJ/Nm^3 from day to day.

To enable leaks from the gas pipes to be detected surely and quickly, a powerful odorizer (e.g. mercaptan) is added to the gas just after the gas leaves the transfer station.

The second stage of pressure reduction, taking place in the pressure reduction station, is located near the point of consumption (Fig. 13). With the exception of the NG heaters it contains about the same equipment as the transfer station. The aim of this installation is to completely even out supply network pressure fluctuations and to set the final pressure according to the requirements of the consumer i.e. the burner and kiln systems.

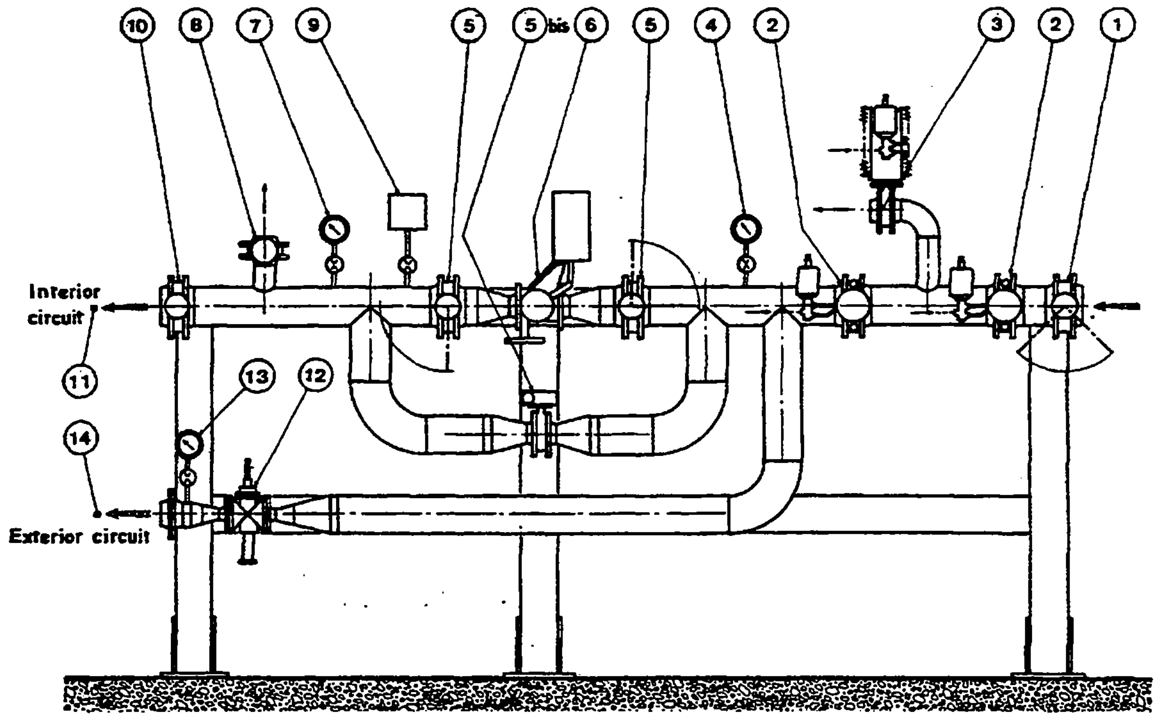
Figure 13: Secondary Pressure Reducing Unit



Immediately before the kiln, the gas stream is split up in order to supply the radial and the axial gas nozzle of the burner (Fig. 14).

Figure: 14: Kiln Ramp Unit

1 Manual shut-off cock
2 Electro-pneumatic shut-off valve
3 Electro-pneumatic vent valve
4 Pressure gauge with cock
5 Regulating valve shut-off cocks
5bis Regulating valve by-pass cock
6 Interior circuit regulating valve
7 Pressure gauge with cock
8 Vent cock
9 Pressure switch with 2 contacts
10 Interior circuit shut-off cock
11 Interior circuit flexible hose
12 Exterior circuit, manual regulating valve
13 Pressure gauge with cock
14 Exterior circuit, flexible hose



4.2 Safety Precautions

4.2.1 Flexible Hoses Bursting

Since there is some risk of the flexible gas hoses between kiln burner and gas supply line bursting or of the proceeding valves etc. failing, pressure monitors for the maximum and minimum pressure are inserted immediately before the hoses concerned. In the event of an emergency stop, a safety stop valve, or two in series, are actuated to stop any further input of fuel at once.

4.2.2 Leak Tests

To check the gas pipes and fittings inside the plant for leaks the following methods are used:

- Normally leaks can be detected naturally as a result of adding odorizer.
- When machines are switched off, the hissing sound of the escaping gas is easily discernible.
- A somewhat riskier method is to run a naked flame along the gas pipe. This results in a flaming torch being produced at the leak, which cannot be overlooked. There is no risk of this flame striking back into the supply pipe (quenching distance, lack of oxygen), but escaped gas could cause an explosion.

When constructing buildings which contain gas pipes, it is essential to allow for sufficient ventilation. This point does not usually give rise to any difficulty in cement works. But to be quite sure, certain items of equipment can be fitted with guard flames from the start. Their task is to ignite any gas that escapes before a large quantity of explosive mixture has a chance to collect.

A further possibility is to install gas detectors in critical places such as the gas preparation station or the burner tunnel.

4.2.3 Explosions in the Kiln

The most important requirement is that the fuel should not be allowed to enter the kiln unintentionally or at an uncontrolled rate, as this is essential to prevent explosions occurring in the kiln itself or in the systems following it (e.g. preheater tower, EP).

This means that the fuel input has to be stopped immediately in the event of the flame going out. In this respect it must be said that extinction of the flame in a hot kiln has never been observed so far, even during material rushes.

Nevertheless during the start up of the cold kiln, lifting off and extinction of the flame can occur, for example caused by partly blocked burneroutlets which lead to increased injection speed of the gas. If the gas is injected with a too high speed, the flame can be blown out.

Therefore careful observation of the flame during the whole start up period is of utmost importance. In the case of the flame going out, fuel supply has to be cut off immediately to prevent explosions.

Excessive fuel input can also cause explosions because of CO accumulations. Therefore careful monitoring of CO concentrations is important.

5. LIST OF REFERENCES

1) "Firing Systems"
VA 82/4898/E

2) "Flames and Burners"
VA 93/4056/E

3) "State of Technology of Rotary Kiln Burners"
F. Schneider, PT 96/14078/E

4) "Proportioning of Bulk Materials"
F Bucher, PT 96/14071/E

5) "A Review of Coal Firing Systems and their Influence on Heat Consumption, Production and Kiln Operation"
H. Meier, PT 96/14210/E